Appendix A

Highway Investment Analysis Methodology

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Investments in highway resurfacing and reconstruction and highway and bridge capacity expansion are modeled by the Highway Economic Requirements System (HERS), which has been used since the 1995 C&P report. This appendix describes the basic HERS methodology and approach in slightly more detail than is presented in Part II, including the treatment of ITS deployment and operations strategies, the allocation of investment across improvement types, and the calculation of the highway backlog. It also explores some of the improvements that have been made to the model since the 2004 C&P report. These include two new procedures, one that links investment levels to revenues and another that simulates the effects of universal congestion pricing, as well as updates to the improvement costs matrix.

Highway Economic Requirements System

The HERS model initiates the investment analysis by evaluating the current state of the highway system using information on pavements, geometry, traffic volumes, vehicle mix, and other characteristics from the Highway Performance Monitoring System (HPMS) sample dataset. Using section-specific traffic growth projections, HERS forecasts future conditions and performance across several funding periods. As used in this report, the future analysis covers four consecutive 5-year periods. At the end of each period, the model checks for deficiencies in eight highway section characteristics: pavement condition, surface type, volume/service flow (V/SF) ratio, lane width, right shoulder width, shoulder type, horizontal alignment (curves), and vertical alignment (grades).

Once HERS determines a section's pavement or capacity is deficient, it will identify potential improvements to correct some or all of the section's deficient characteristics. The HERS model evaluates seven kinds of improvements: resurfacing, resurfacing with shoulder improvements, resurfacing with widened lanes (aka minor widening), resurfacing with added lanes (aka major widening), reconstruction, reconstruction with widened lanes, and reconstruction with added lanes. For improvements that add travel lanes, HERS further distinguishes between those that can be made at "normal cost" and those on sections with limited widening feasibility that could only be made at "high cost." HERS may also evaluate alignment improvements to improve curves, grades, or both.

Q&A

Where can I find more detailed technical information concerning the HERS model?

The Federal Highway Administration (FHWA) has previously developed a *Technical Report for the Highway Economic Requirements System*. The most recent printed edition, dated December 2000, is based on HERS version 3.26, which was utilized in the development of the 1999 edition of the C&P report.

The FHWA also has developed a modified version of HERS for use by states. This model, HERS-ST, builds on the primary HERS analytical engine, but adds a number of customized features to facilitate analysis on a section-by-section basis. The recently released HERS-ST version 4.0 is largely based on HERS version 4.097, which was utilized in developing the 2004 edition of the C&P report. The Highway Economic Requirements System–State Version: Technical Report is available online at http://www.fhwa.dot.gov/infrastructure/asstmgmt/hersdoc.htm. Any updates to the HERS-ST model, including those designed to incorporate new features developed for HERS, will be reflected in future editions of the Technical Report.

When evaluating which potential improvement, if any, should be implemented on a particular highway section, HERS employs incremental benefit-cost analysis. The HERS model defines benefits as reductions in direct highway user costs, agency costs, and societal costs. Highway user benefits are defined as reductions in travel time costs, crash costs, and vehicle operating costs. Agency benefits include reduced maintenance costs (plus the residual value of projects with longer expected service lives than the alternative). Societal benefits include reduced vehicle emissions. Increases in any of these costs resulting from a highway improvement (such as higher emissions rates at high speeds or the increased delay associated with a work zone) would be factored into the analysis as a "disbenefit."

These benefits are divided by the costs of implementing the improvement to arrive at a benefit-cost ratio (BCR) that is used to rank potential projects on different sections. The HERS model implements improvements with the highest BCR first. Thus, as each additional project is implemented, the marginal BCR and the average BCR of all projects implemented decline. However, until the point where the marginal BCR falls below 1.0 (i.e., costs exceed benefits), total net benefits will continue to increase as additional projects are implemented. Investment beyond this point would not be economically justified, since it would result in a decline in total net benefits.

Because the HERS model analyzes each highway segment independently, rather than the entire transportation system, it cannot fully evaluate the network effects of individual highway improvements. While efforts have been made to indirectly account for some network effects, HERS is fundamentally rooted to its primary data source, the national sample of independent highway sections contained in the HPMS. To fully recognize all network effects, it would be necessary to develop significant new data sources and analytical techniques. The Part IV Afterword includes more discussion of this issue.

Q&A

What are the average and marginal benefit cost ratios associated with the HERS scenarios presented in this report?

The HERS analysis presented in this report was performed by imposing a funding constraint on the model. Under this type of analysis, HERS ranks potential improvements in order by their benefit-cost ratios, then implements them until the funding constraint is reached (see the Introduction to Part II). Higher funding levels will thus include projects with lower benefit-cost ratios, both at the margin (when the constraint is met) and on average.

For the "Maintain User Costs" scenario, the average benefit-cost ratio was 5.69. The marginal benefit-cost ratios in each of the four funding periods ranged from 2.43 to 3.08. For the "Maximum Economic Investment" scenario, the average BCR was 3.14, and the marginal BCRs ranged from 1.00 to 1.84.

Allocating HERS and NBIAS Results Among Improvement Types

Highway capital expenditures can be divided among three types of improvements: system rehabilitation, system expansion, and system enhancements (see Chapters 6 and 7 for definitions and discussion). All improvements selected by HERS that did not add lanes to a facility were classified as part of system preservation. For improvements that added lanes, the total cost of the improvement was split between preservation and expansion, since widening projects typically improve the existing lanes of a facility to some degree. Also, adding new lanes to a facility tends to reduce the amount of traffic carried by each of the old lanes, which may extend their pavement life. The allocation of widening costs between preservation and capacity expansion was based on the improvement cost inputs and implementation procedures within the HERS model.

All investment scenarios projected by the National Bridge Investment Analysis System (NBIAS) are classified as rehabilitation only, since new bridge and bridge capacity expansion investments are implicitly modeled by HERS. The HERS model does not currently analyze investments in those types of improvements classified as system enhancements.

Highway Investment Backlog

To calculate this value, HERS evaluates the current state of each highway section before projecting the effects of future travel growth on congestion and pavement deterioration. Any potential improvement that would correct an existing pavement or capacity deficiency, and that has a BCR greater than or equal to 1.0, is considered to be part of the current highway investment backlog.

As noted in Chapter 7, the backlog estimate produced by HERS does not include either rural minor collectors or rural and urban local roads and streets (since HPMS does not contain sample section data for these functional systems), nor does it contain any estimate for system enhancements.

Travel Demand Elasticity

The States furnish projected travel for each sample highway section in the HPMS dataset. As described in Chapters 7 and 9, HERS assumes that the HPMS forecasts are constant-price forecasts, meaning that the generalized price facing highway users in the forecast year is the same as in the base year. The HERS model uses these projections as an initial baseline, but alters them in response to changes in highway user costs on each section over time. The travel demand elasticity procedures in HERS recognize that as a highway becomes more congested, some potential travel on the facility may be deterred and, that when lanes are added to a facility, the volume of travel may increase.

The basic principle behind demand elasticity is that, as the price of a product increases relative to the price of other products or services, consumers will be inclined to consume less of it. Conversely, if the price of a product decreases, consumers will be inclined to consume more of it, either in place of some other product or in addition to their current overall consumption.

The travel demand elasticity procedures in HERS treat the cost of traveling a facility as its price. As a highway becomes more congested, the cost of traveling the facility (i.e., travel time cost) increases, which tends to constrain the volume of traffic growth. Conversely, when lanes are added and highway user costs decrease, the volume of travel tends to increase.

Q&A

What are some examples of the types of behavior that the travel demand elasticity features in the HERS represent?

If highway congestion worsens in an area, this increases travel time costs on the road network. In response, some highway users might shift their trips to mass transit or perhaps forgo some personal trips they might ordinarily make. For example, they might be more likely to combine multiple errands into a single trip because the time spent in traffic on every trip discourages them from making a trip unless it is absolutely necessary.

In the longer term, people might make additional adjustments to their lifestyles in response to changes in user costs that would impact their travel demand. For example, if travel time in an area is reduced substantially for an extended period of time, some people may make different choices about where to purchase a home. If congestion is reduced, purchasing a home far out in the suburbs might become more attractive, since commuters would be able to travel farther in a shorter period of time.

As a result of travel demand elasticity, the overall level of highway investment has an impact on projected travel growth. For any highway investment scenario that results in a decline in average highway user costs, the effective vehicle miles traveled (VMT) growth rate tends to be higher than the baseline rate. For scenarios in which highway user costs increase, the effective VMT growth rate tends to be lower than the baseline rate. However, this effect has been tempered to some degree by the new HERS revenue procedures described below, which increase user fees at higher levels of investment and thus dampen the effect of highway performance improvements on travel demand.

Demand elasticity is measured as the percentage change in travel relative to the percentage change in costs faced by users of the facility. Thus, an elasticity value of –0.8 would mean that a 10 percent decrease in user costs would result in an 8 percent increase in travel.

Operation Strategies and ITS Deployment

One of the key modifications to HERS featured in the previous report was the ability to consider the impact of highway operations strategies and intelligent transportation system (ITS) deployments on highway system performance. This feature is continued in this report with only minor modifications. Current and future investments in operations are modeled outside of HERS, but the impacts of these deployments were allowed to affect the internal calculations made by the model, and thus also affect the capital improvements considered and implemented in HERS. As discussed in Part IV, a longer-term goal would be to analyze operations as alternative investment strategies directly in HERS.

While numerous operations strategies are available to highway authorities (see Chapter 15), a limited number are now considered in HERS (based on the availability of suitable data and empirical impact relationships). The types of strategies analyzed can be grouped into three categories: arterial management, freeway management, and incident management as follows:

- Arterial Management
  - Signal Control
  - Electronic Roadway Monitoring
  - Variable Message Signs (VMS)
- Freeway Management
  - Ramp Metering (preset and traffic actuated)
  - Electronic Roadway Monitoring
  - VMS
- Incident Management
  - Incident Detection (free cell phone call number and detection algorithms)
  - Incident Verification (surveillance cameras)
  - Incident Response (on-call service patrols).

Creating the operations improvements input files for use in HERS involved four steps: determine current operations deployment, determine future operations deployments, determine the cost of future operations investments, and determine the impacts of operations deployments.

Current Operations Deployments

To determine current operations deployments on the HPMS sample segments, data were used from three sources: HPMS universe data, HPMS sample data, and the ITS Deployment Tracking System. The data assignments that were made reflected the fact that operations deployments occur over corridors (or even over entire urban areas, as with traffic management centers).

Future Operations Deployments

For future ITS and operations deployments, three scenarios were developed. For the "Continuation of Existing Deployment Trends" scenario, an examination of current congestion levels compared with existing deployments was made to set the congestion level by urban area size for each type of deployment. For the "Aggressive Deployment" scenario, an accelerated pace of deployment above existing trends was assumed. The hypothetical "Full Deployment" scenario illustrates the maximum potential impact of the strategies and technologies modeled in HERS on highway operational performance.

Operations Investment Costs

The unit costs for each deployment item were taken from the U.S. Department of Transportation's (DOT's) *ITS Benefits Database and Unit Costs Database* and supplemented with costs based on the ITS Deployment Analysis System (IDAS) model. Costs were broken down into initial capital costs and annual operating and maintenance costs. Also, costs were determined for building the basic infrastructure to support the equipment, as well as for the incremental costs per piece of equipment that is deployed. A major addition to operations deployment costs in this report is the inclusion of traffic signal replacement costs, which were not previously considered in the estimated capital costs.

Impacts of Operations Deployments

Exhibit A-1 shows the estimated impacts of the different operations strategies considered in HERS. These effects include the following:

- Incident Management: Incident duration is reduced as well as the number of crash fatalities. Incident duration is used as a predictor variable in estimating incident delay in the HERS model.

- Signal Control: The effects of the different levels of signal control are directly considered in the HERS delay equations.

- Ramp Meters and VMS: Delay adjustments are applied to the basic delay equations in HERS.

Based on the current and future deployments and the impact relationships, an operations improvements input file was created for each of the two deployment scenarios. The file contains section identifiers, plus current and future values (for each of the four funding periods in the HERS analysis) for the following five fields:

- Incident Duration Factor
- Delay Reduction Factor
- Fatality Reduction Factor
- Signal Type Override
- Ramp Metering.

Exhibit A-1

Impacts of Operations Strategies in HERS

Operations Strategy	Impact Category	Impact
Arterial Management		
Signal Control	Congestion/Delay	Signal Density Factor = n(nx+2)/(n+2) where n = # of signals per mile x = 1 for fixed time control 2/3 for traffic actuated control 1/3 for closed loop control 0 for real-time adaptive control/SCOOT/SCATS Signal Density Factor is used to compute zero-volume delay due to traffic signals
Electronic Roadway Monitoring	Congestion/Delay	Supporting deployment for corridor signal control (2 highest levels)
EM Vehicle Signal Preemption		
VMS	Congestion/Delay	-0.5% incident delay
Freeway Management		
Ramp Metering		
Preset	Congestion/Delay	New delay = 0.16 hrs per 1000 VMT – 0.13(original delay)
Traffic Actuated	Congestion/Delay Safety	New delay = 0.16 hrs per 1000 VMT – 0.13(original delay) -3% number of injuries and PDO accidents
Electronic Roadway Monitoring	Congestion/Delay	Supporting deployment for ramp metering and Traveler Info
VMS	Congestion/Delay	-0.5% incident delay
Incident Management		
Detection Algorithm/ Free Cell	Incident Characteristics Safety	-4.5% incident duration -5% fatalities
Surveillance Cameras	Incident Characteristics Safety	-4.5% incident duration -5% fatalities
On-Call Service Patrols	Incident Characteristics Safety	-25% incident duration -10% fatalities
All Combined	Incident Characteristics Safety	Multiplicative reduction -10% fatalities

HERS Revenue and Pricing Analysis

The most important revisions to the HERS analytical procedures for this report involve highway revenue and pricing analysis. The conceptual basis for these changes and their impacts on the C&P investment analysis are highlighted throughout the report. While these two procedures address related issues, they are implemented distinctly from one another within the model.

Revenue Analysis

The HERS revenue analysis procedures provide the option of imposing a "balanced budget" constraint on the results. This was done by creating a mechanism to link the HERS levels of investment to the additional revenue that would be required to fund that investment.

The first step in the procedure is to determine the amount of revenue that is required to be raised. This calculation is based on the difference between the funding constraint specified for the run and base year HERS-related expenditures, which were calculated from 2004 highway capital expenditure data. A multiplier is then applied to this difference to ensure that revenues would be sufficient to cover other capital expenditure types (including bridge rehabilitation and replacement and system enhancement) that are not modeled in HERS.

The model assumes that any additional revenues needed to support the scenario being analyzed are raised through user surcharges in a manner consistent with the current financing structure. The surcharge tax rate is calculated by simply estimating total VMT and fuel consumption, then dividing this into the amount of required revenue.

The revenue and surcharge calculations are repeated sequentially for each funding period. However, during the benefit-cost analysis in each period (which typically extends over multiple periods), HERS assumes that the surcharge tax rates in that period are carried forward into future periods.

Congestion Pricing

Preliminary results from the new HERS congestion pricing feature are presented in Chapter 10. This procedure has been newly developed for this edition of the C&P report and has not yet been subject to extensive testing. When invoked in the model, it estimates and applies a user fee based on the level of congestion on each section.

The congestion pricing feature was constructed using the existing HERS procedures for calculating delay and travel demand. HERS first calculates average user costs in its usual fashion, then derives the marginal congestion cost from the delay equations (coupled with value of time inputs). The difference between average costs and marginal costs represents the estimated congestion externality that each additional vehicle imposes on other users. The model then applies a toll equal to this cost differential, forcing users to "internalize" the externality (and improving efficiency) and determines a new equilibrium volume and price. The congestion pricing procedure is applied to peak period traffic on all roads with a volume/capacity ratio of 0.80 or greater. This is the threshhold used in Chapters 4 and 9 to identify roads as being congested.

It is important to understand that the congestion pricing feature does not operate in conjunction with any of the revenue analysis features described above. As a result, the HERS considers the "revenues" raised by the congestion tolls to be in addition to existing user fees, rather than as a replacement for them.

HERS Improvement Costs

For the 2004 C&P report, significant changes were made to the structure of the HERS improvement cost matrix, the assumed unit costs in that matrix, and the manner in which those values were applied. This updating process was continued for this report, though the incremental changes were less extensive than in the prior report.

The improvement cost updates reflected in the 2004 report were based on highway project data from six states (see Appendix A of that report for more information). Though adequate in most respects, that dataset was relatively thin in certain key areas. For the purposes of this update, additional data were collected focusing on three of these areas: mountainous regions, large urbanized areas, and high-cost capacity improvements.

The 2004 update had disaggregated the improvement cost values in urban areas by functional class and by urbanized area size. Three population groupings were used: small urban (5,000 to 49,999), small urbanized (50,000 to 200,000), and large urbanized (over 200,000). However, the data used to create values for the latter group did not include a significant number of projects in very large urbanized areas, and concerns had been raised about the degree of construction cost comparability between medium-sized cities and much larger ones. For the update in this report, more project cost data were collected, specifically focusing on major urbanized areas over 1 million in population, and a new category for these areas was added to the cost table.

For rural areas, separate cost values are applied by terrain type and functional class. Because projects in mountainous areas were not well represented in the data used in the previous update, additional information was collected from such areas, and the cost items for this terrain type were revised.

Unit values for high-cost transportation capacity improvements ("high cost lanes" in HERS) were modified for the 2004 report. However, these values were again based on a limited number of data sources. To improve these estimates, FHWA collected data on a larger number of projects of the type that these HERS improvements are intended to represent, including parallel routes, double-decking, tunneling, or purchasing extremely expensive right of way.

HERS Technical Reviews

Peer reviews by panels of outside experts are an effective way to ensure that the methodologies and analytical tools used in the C&P report continue to meet acceptable standards of technical merit. Under the Office of Management and Budget's *Final Information Quality Bulletin for Peer Review*, such reviews are also required for any "highly influential scientific disseminations," a category that has been deemed to include the C&P analytical tools, including HERS and NBIAS.

In its early development, the HERS model received extensive scrutiny from various technical panels that looked at all aspects of the modeling procedure in depth. More recent reviews focused on specific aspects of the model. The last such review was conducted in 1999 and focused on the travel demand elasticity procedures and emissions procedures.

The FHWA has recently completed a new round of technical evaluations of HERS, concentrating on major features added to the model that would be especially well suited for outside review. The chosen focus areas were the HERS ITS/operations analytical procedures, and recent modifications to the HERS elasticity procedures (see Appendix A in the 2004 and 2002 C&P reports for more information on these model enhancements). To conduct the reviews, FHWA hired a contractor to assemble two panels, consisting of three members each, to examine different aspects of the model. A third panel was created to examine the NBIAS model (see Appendix B). The final reports from each of the panels are available at http://www.dot.gov/peerrt.htm.

The HERS Elasticity panel consisted of university researchers with extensive experience in the modeling of travel demand. The panel reviewed the documentation on the HERS elasticity procedures. While the panelists individual reviews focused on refinements made to the procedures to account for vehicle occupancy, section length, and diversion, they considered other aspects of the HERS elasticity approach as well. They noted the difficulties involved in attempting to apply travel demand concepts on a segment-based model, and questioned the assertion that diversionary impacts on other roadways could be ignored both theoretically and practically. They noted the conceptual differences between network-level elasticities and link-level elasticities, and the challenge in navigating between the two for the HERS analysis. One review also raised issues with the manner in which short-run and long-run elasticity effects are operationalized in HERS.

One modification that has been made for this report based on the panel's review was to reduce the elasticity parameter values used in HERS. The concern was that the older values might be too high given the nature of the data used in HERS, which are sample segments intended to represent larger portions or corridors on different functional classes. The lower values used in this report (−0.4 for short-run elasticity and −0.8 for long-run elasticity) are believed to be better representations of corridor-level effects. Chapter 10 includes an analysis of the effect that this parameter change has on the investment scenario estimates.

The peer reviewers of the HERS Operations procedures included experts in highway congestion modeling and ITS development and deployment. The reviewers concluded that the basic approach used to estimate current and future ITS deployment was sound, but that it was limited by the quality of the data sources. They also determined that the impacts of ITS and operations strategies on highway operational performance that are assumed in HERS were reasonable, but that they should continue to be updated as new research on these impacts becomes available. They also made several suggestions about changes to existing data sources that would improve the quality of the analysis. These suggestions are being considered as part of FHWA's current reassessment of the HPMS data process (see the Afterword in Part IV).